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For: A BACKLIGHTING LIGHT PIPE FOR ILLUMINATING A FLAT-PANEL DISPLAY

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Attached please find the certified copy of the foreign application from which priority is claimed for this case:

Country	**: Finland**
Application Number	**: 982825**
Filing Date	**: 30 December 1998**

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PRIORITY DOCUMENT

Hakija Applicant	**Nokia Mobile Phones Ltd** **Espoo**
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Kansainvälinen luokka International class	**G09F**
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"A backlighting light pipe for illuminating a flat-panel display"
(Taustavalaistuksen valonjohdin litteälle näytölle)

Täten todistetaan, että oheiset asiakirjat ovat tarkkoja jäljennöksiä patentti- ja rekisterihallitukselle alkuaan annetuista selityksestä, patenttivaatimuksista, tiivistelmästä ja piirustuksista.

This is to certify that the annexed documents are true copies of the description, claims, abstract and drawings originally filed with the Finnish Patent Office.

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A backlighting light pipe for illuminating a flat-panel display

Taustavalaistuksen valonjohdin litteälle näytölle

En bakgrund ljusledare för en flat dataskärm

The invention relates to a very thin light pipe with light control for illuminating a flat-panel display from the backside of the display as evenly as possible.

A formerly known conventional light pipe is used for illuminating a flat-panel display by conducting light from a light source using a randomly roughened surface to form an even illumination to the display. When the light pipe is made thick, the display is lighted quite evenly, whereas making the light pipe thinner causes visible, more intensively lighted areas close to the light sources. The light pipe must be made thin because of the small size of many electronic equipment used nowadays. The illumination becomes more uneven mainly as a result of light reflecting increasingly from the bottom and the top of the guide when propagating in a thinner space from the source end to the other end. Only a part of the light is conducted directly to the roughened surface from the source. Most of the light is reflected many times from the roughened surface and weakened when reflected. The light input from an end of a perfectly polished light pipe would reflect completely from all surfaces.

Figure 1A represents a known arrangement for lighting a flat-panel display 1 with a randomly roughened light pipe 3. Outcoupled light rays 2 are stronger near the light source L1. Roughened surface is usually under the light pipe 3 and the part of the light transmitted through the surface is reflected back from a reflector 4 that is placed under the light pipe 3. Most of the reflected light is then transmitted through a clear top surface of the pipe because of the angle of incidence being less than required for complete reflection. Figure 1B represents the random nature of the roughened light pipe. The horizontal axis shows the length of the light pipe in millimetres and the vertical axis shows the outcoupling efficiency η. The out-coupling efficiency η is constant along the horizontal axis. Figure 1C represents the brightness B of the randomly roughened light pipe decreasing towards the end of the light pipe when the light source L1 is placed at the left end. Figure 1D represents how the light 5 from the light source L1 propagates inside the light pipe 3 as rays

5A - E, 6A, B of light. Rays 5A - E reflected with same angles of incidence are shown with continuous lines. It is shown how light is transmitted out from five different places. The nearest ray 5A of light is the most efficient being closest to the light source and reflected only once from the roughened surface. The following rays 5B - E of light are less efficient because of more reflections from the roughened surface in the light pipe. Every reflection from the roughened surface causes some transmittance that weakens the light ray. If the transmittance is 30%, the light input is weakened on every reflection to 0.7 compared to the light before reflection. Only five complete rays of light or routes of light are represented in the figure though in reality transmitted light comprises an infinite number of reflected light rays. Two of these other routes 6A, 6B are presented with dashed lines.

A formerly known controlled light pipe is used for illuminating the display evenly by conducting light through a surface where the transmission factor of the surface is reduced near the light source. A pattern of small dots on top or bottom of the light pipe are used to increase the outcoupling efficiency η outwards the end of the light source. These dots are, for example, small lenses.

Figure 2 represents a known arrangement for lighting a flat-panel display 7 with a light pipe 9. The light pipe 9 has a controlled surface. The rays 8 of light are stronger close to the light source L2 because of less outcoupling before the point of consideration. The effect of the controlled surface of the light pipe 9 is that the light is allowed to transmit to a reflector 10 under the light pipe 9 to reflect back and to the display 7 only through few areas or some of the lenses close to the light source where the light is strong. The density of the lenses increases towards end of the light pipe. This increase of density makes the outcoupling efficiency η to increase. If the controlled surface is on the top, no reflector is used and light is coupled out only through the top. This causes bright visible spots that also lead light to an unfavorable direction.

A problem with the formerly known controlled light pipe is that it is almost impossible to simulate the total effect of the dots to the transmission of light when designing the light pipe. The size of the dots should be of visible dimension to be simulated fairly. The amount of invisible dots on a controlled surface is many thousands and is impossible to simulate. Many prototypes have to be made to achieve an acceptable result. The results have still not been optimal.

Another formerly known technique for achieving more even illumination is to increase the number of light sources. The light sources are positioned preferably at opposite sides of the light pipe. The problem is that more light sources means more current needed. Another problem is that to some extent illumination remains unequal.

The objective of the present invention is to present a new light pipe, which is easy to manufacture and can be used to form even illumination to the display.

The invention concerns a backlighting light pipe for illuminating a flat-panel display, with at least one light source, at least one surface of the light pipe being formed with a diffractive structure to control an amount of light directed to the flat-panel display with diffractive optics. According to the invention value of at least one parameter defining the diffractive structure is a function of location on the surface area to control outcoupling of light on the surface area.

In consequence of the invention, outcoupled energy is controlled by means of diffractive optics to increase the outcoupling efficiency η towards the end opposite to the light source end. By increasing the outcoupling efficiency η at the same rate as the light energy decreases towards the end, the effects can be compensated. As an advantage of the invention, even illumination of the display is achieved as the result.

The local outcoupling efficiency is preferably controlled by changing one or several parameters that define a local profile of the diffractive structure. The profile can be at least binary, sine or triangular formed. To the profile applicable parameters as period d, fill factor c and/or height h are controlled.

The diffractive surface of the light pipe can be made at least by using electron beam nanolitography directly on the surface or on a mold for moulding the light pipe. A preferable material for the light pipe is polymethyl-methacrylate PMMA. An advantage of the invention is its suitability for massproduction because of easy moulding of the diffractive surface using same kind of extrusion method as for the known light pipes. A further advantage of the invention is that a prototype can be made in few hours for testing and making corrections. The elaboration cycle of the light pipe is efficient with theoretical estimation. The prototype can be made by constructing a narrow diffractive structure on a substrate of the preferred material. Another further advantage of the invention is that the diffraction pattern is indiscernible.

Preferable embodiments are presented in the dependent claims.

The invention is described in detail in the following with reference to the attached drawings, where

figure 1 represents a known arrangement for random lighting,

figure 2 represents a known arrangement for controlled lighting,

figure 3 represents an arrangement with a light pipe according to the invention,

figure 4 represents a detail of a light pipe according to the invention,

figure 5 represents diffraction and reflection of light in a light pipe according to the invention,

figure 6 represents outcoupling efficiency η of the diffractive surface,

figure 7 represents light pipes with diffractive structures from above, and

figure 8 represents different shapes of diffractive structures.

Figures 1 and 2 are described with background art above.

Figure 3A represents an arrangement for lighting a flat-panel display 11 with a light pipe 13 according to the invention. The light pipe 13 has a diffractive controlled surface comprising local gratings with different grating parameters. The local gratings are situated on differently located areas of the surface. The gratings according to this embodiment are binary. Rays 12 of light are evenly positioned and of the same strength although the luminance inside the light pipe 13 is higher closer to the light source L3, 13A than the other end 13B. The outcoupling efficiency η of the transmitted light is controlled using a filling factor of a local binary grating 13C on the diffractive controlled surface. A preferably Lambertian white reflector 14 is placed under the light pipe 13 according to the invention to reflect back to the light pipe 13 the light transmitted through the bottom of the light pipe.

Figure 3B represents the controlled nature of the light pipe according to the invention. The horizontal axis shows the length of the light pipe in millimetres and

the vertical axis the outcoupling efficiency η. The outcoupling efficiency η increases expotentially towards the end of the light pipe along the horizontal axis.

Figure 3C represents the brightness B of the controlled light pipe according to the invention being constant from one end of the light pipe to the other.

The horizontal scale from 0 to 30 mm in the figures 3B and 3C is only exemplary. The longitudinal dimension of the display and the light pipe can differ from this lengt.

Figure 3D represents how the light 15 from the light source L3 propagates inside the light pipe 13 as rays 15A - E, 16A, B of light. Rays 15A - E reflected with same angles of incidence are shown with continuous lines. Light transmitted out from five different places are represented. The nearest ray 15A of light is the most intense inside the light pipe being closest to the light source and reflecting only once. Because of the intensity of the ray 15A of light, the diffractive surface is designed to let only a tiny fraction of the light transmitted through the surface. The following rays 15B - E of light are less intense inside the light pipe because of more reflections. Because the intensity of the rays 15B - E of light is lower inside the light pipe, the diffractive surface is designed to let a larger fraction of the light transmitted out through the surface. Only five complete rays of light or routes of light are represented in the figure though in reality transmitted light comprises an infinite number of reflected light rays. Two of these other routes 16A, 16B are presented with dashed lines.

Figure 4 represents the geometry of the diffractive surface of the light pipe according to a preferable embodiment of the invention. This detail of the diffractive surface is a phase of the binary grating forming the diffractive surface. The measures are period d, fill factor c and groove height h. Index n_1 is refractive index of the light pipe and index n_2 is refractive index of the material between the light pipe and the display to be lighted. The latter material is usually air.

Figure 5A represents diffraction and reflection of light in a light pipe according to the invention. A light ray with an incidence of α is treated. Most of the light is reflected back to the light pipe from the top and all from the bottom surface. In the dashed right-angled parallelogram 17, a period of diffractive structure and how some of the light is diffracted out of the light pipe is represented.

Figure 5B represents an enlargement of details in the parallelogram 17. The ray of light enters with an incidence of α. The diffraction occurs in transmitted and reflected orders. Their angles are correspondingly β_{pT} and β_{pR}. The transmitted orders are numbered from -2_T to -10_T and the reflected orders from 0_R to -12_R. The reflection order 0_R is a normal reflection with the same incidence angle as the entered ray.

Figure 6 represents the outcoupling efficiency η of the diffractive surface relative to angles of incidence and function of the fill ratio c/d. The continuous line is the result from an angle α of incidence being 60°, the dashed line from 70° and the dotted line from 80°. The results are obtained by calculating averages for TE (Transverse Electric wave) and TM (Transverse Magnetic wave) modes of propagation. Directly transmitted and advantageously reflected rays are included in calculation. Absorption in the white rear reflector material is not included in the calculation.

Figure 7 represents two light pipes with different areal diffractive structure layouts from above. In the figure 7A is a diffractive structure 18 with transverse grooves seen and in the figures 7B and 7C are diffractive structures 19, 20 with curved grooves seen. The parameters of the diffractive structures are controlled on the central line that is shown with a dashed break-line A-B in the all structures. The break-line A-B represents grooves C and ridges of the structure by being down for a groove C and up for a ridge although the figure is seen from above. The curved grooves in the figure 7B are adjusted to the distance from the light source L5 by setting the pivot D of the curves on the light source. The curved grooves in the figure 7C are waveshaped to form random effect of lighting to avoid bright disturbing lines seen on the surface caused by the light L6. As light sources L4, L5, L6 are usually round light emitting diodes LED used.

In all the figures 1A, 2, 3A, 5A, 7A, 7B and 7C the diffractive structure is much bigger relative to the thickness than in reality. This is made to illustrate the diffractive structures that are very thin.

Figure 8 represents alternative structures of grating for the diffractive surface from sideview with adjustable parameters of that type. Figure 8A represents a binary grating with parameters height h, period d and fill factor c. Figure 8B represents a continuous sine form grating with parameters height h and period d. Also the fill factor of the sine form grating can be controlled by changing a coefficient relative to

the distance. Figure 8C represents a multilevel scaled grating with parameters heights h_1, h_2, period d and fill factors c_1, c_2.Figure 8D represents a triangular profile grating with parameters height h and period d. The angles of the triangular blade can be controlled by changing the parameters. Other grating profiles are also possible.

The grating law for each diffraction order is, for transmitted orders

$$\sin\beta_{pT} = \frac{p\lambda}{n_2 d} + \frac{n_1}{n_2}\sin\alpha \qquad (1)$$

and for reflected orders

$$\sin\beta_{pR} = \frac{p\lambda}{n_1 d} + \sin\alpha \qquad (2),$$

where α is the angle of incidence of the entering light, β_{pT} is the angle of incidence of the transmitted diffraction order p, β_{pR} is the angle of incidence of the reflected diffraction order p, and p is the number of the mentioned diffraction order, λ is a wavelength of the entering light, n_1 is the refraction index of the diffractive structure material, n_2 is the refraction index of the surrounding material and d is the period of the diffractive structure.

Relative brightness law in terms of diffraction parameters and distance from the light source can be derived on grounds of the following book: Micro-Optics: Elements, systems and applications, edited by Hans Peter Herzig, Taylor & Francis, 1997 and specifically chapter 2: Diffraction Theory of Microrelief Gratings by Jari Turunen.

This technique is also described in the publication: Illumination light pipe using micro-optics as diffuser, Proceedings Europto series, Holographic and Diffractive Techniques, SPIE 2951, 146-155, 1996, which is incorporated herein by reference.

The following example is presented to explain the invention. A prototype of a light pipe is made for lighting a real flat-panel display. The diffractive structure is designed for light of 570 nm wavelength. The prototype is designed for three light

sources at the end of the light pipe. Optimized grating parameters for a prototype light pipe are calculated and presented in the following table:

Measure	Value
Period d	2.5396 μm
Groove height h	0.5311 μm
Fill ratio c/d	0.2 - 0.5

The period of grating to form a diffractive surface is preferably within a range of 1.5 μm to 3.5 μm. The height of grooves to form a diffractive surface is preferably within a range of 0.3 μm to 0.7 μm. It is also possible to vary the period of the grating and the height of the grooves on the surface to control the outcoupling of light. Changing the period of the grating can be used to control the amount of outcoupled orders and angles of light. Angular distribution of the light near the light source is larger than in the other end of the pipe. The period of grating can be used to even intensity distribution on the surface.

Also a complex structure could be used to reflect the light from the surface at the same time dividing in many orders. This would distribute the light more even but is difficult to design. This kind of technique in free-space optics is presented at least in the following two publications: Noponen et al. "Synthetic diffractive optics in the resonance domain", J. Opt. Soc. Am. A9, 1206-1213 (1992) and Vasara et al., Applied Optics 31, 3320-3336 (1992).

The diffractive structure can be on the surface of one side or both sides of the light pipe. The invention is most suitable to essentially monochromatic light. At least a Liquid Crystal Display LCD technique is appropriate for a flat-panel display mentioned above. The light source can be at least a Light Emitting Diode LED.

Claims

1. A backlighting light pipe for illuminating a flat-panel display (11), with at least one light source, at least one surface of the light pipe being formed with a diffractive structure to control an amount of light directed to the flat-panel display (11) with diffractive optics, the diffractive structure being defined with parameters, **characterized** in that value of at least one parameter defining the diffractive structure is a function of location of differently located areas of the surface (13C) to control outcoupling of light on the areas.

2. A backlighting light pipe according to claim 1, **characterized** in that the diffractive structure is defined with the following local grating parameters: period (d) and height (h) of grooves, and that at least one of the parameters is set individually on differently located areas of the surface (13C) to control outcoupling of light on the areas (13C).

3. A backlighting light pipe according to claim 2, **characterized** in that the diffractive structure (17) is defined also with a parameter fill factor (c) and a fill ratio (c/d) of the grooves, where the value of fill ratio (c/d) is the value of the fill factor (c) divided by the value of the period (d), and the fill ratio (c/d) is adjusted as a function of the distance from the light source (L3, L4, L5) to control the amount of light that is coupled out.

4. A backlighting light pipe according to claim 3, **characterized** in that the fill ratio (c/d) is within a range of 0.2 to 0.5.

5. A backlighting light pipe according to claim 3, **characterized** in that the fill ratio (c/d) is designed to increase from the end (13A) of the light source (L3) to the opposite end (13B) of the light pipe (13).

6. A backlighting light pipe according to claim 5, **characterized** in that the fill ratio (c/d) is increased on a central line of the light pipe from the light source (L4, 18A) to the other end (18B) and the grooves (18C) are transverse to the central line.

7. A backlighting light pipe according to claim 5, **characterized** in that the fill ratio (c/d) is increased on a central line of the light pipe from the light source (L5, 19A) to the other end (19B) and the grooves (19C) are curved as to form a constant distance from the light source to the groove.

8. A backlighting light pipe according to claim 2, **characterized** in that the period (d) of diffractive structure (17) to form a diffractive surface (13C) is within a range of 1.5 μm to 3.5 μm.

9. A backlighting light pipe according to claim 2, **characterized** in that the height (h) of grooves forming the diffractive surface (13C) is within a range of 0.3 μm to 0.7 μm.

10. A backlighting light pipe according to claim 1, **characterized** in that the light pipe is designed for three light sources.

(57) Abstract

The invention relates to a backlighting light pipe (13) for illuminating a flat-panel display (11) with light control. According to the invention the light pipe (13) comprises a diffractive diffusing surface (13C) to control the amount of light transmitted through an area of the surface (13C). In consequence of the invention outcoupled energy is controlled by means of diffractive optics to increase the outcoupling (12) efficiency η towards the end (13B) opposite to the light source (L3) end (13A). By increasing the outcoupling efficiency η at the same rate as the light energy decreases towards the end (13B) the effects are compensated. As an advantage of the invention, even illumination of the display (11) is achieved.

Figure 3A

PRIOR ART

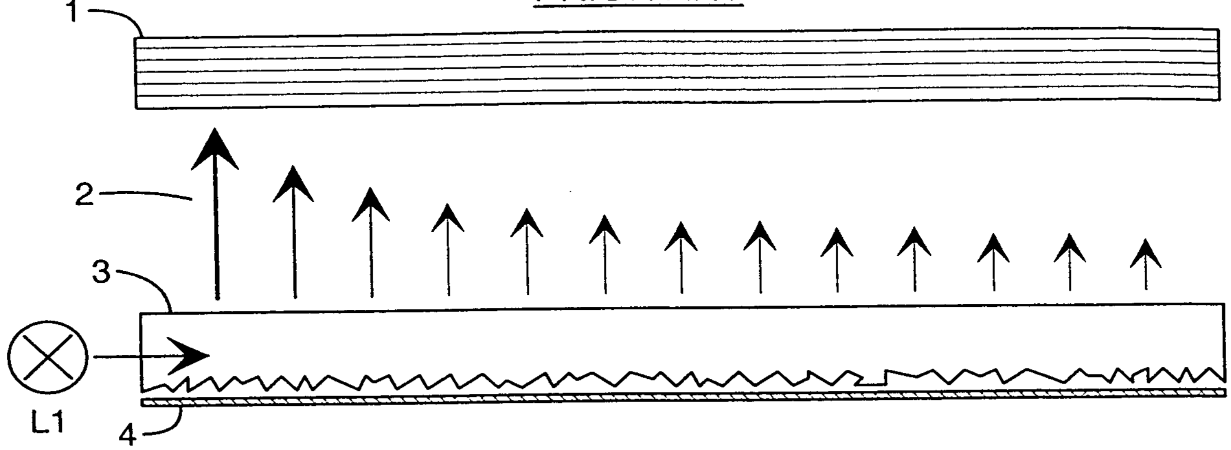

FIGURE 1A

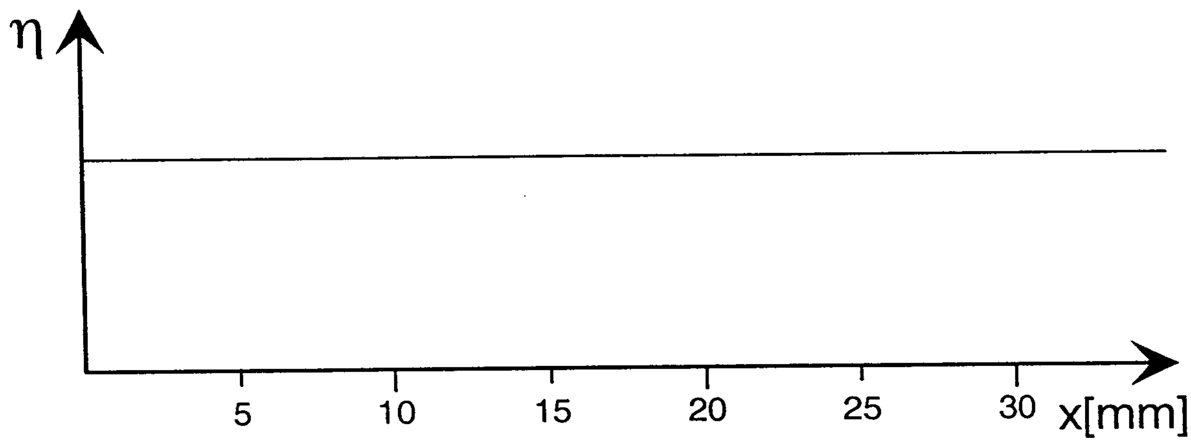

FIGURE 1B

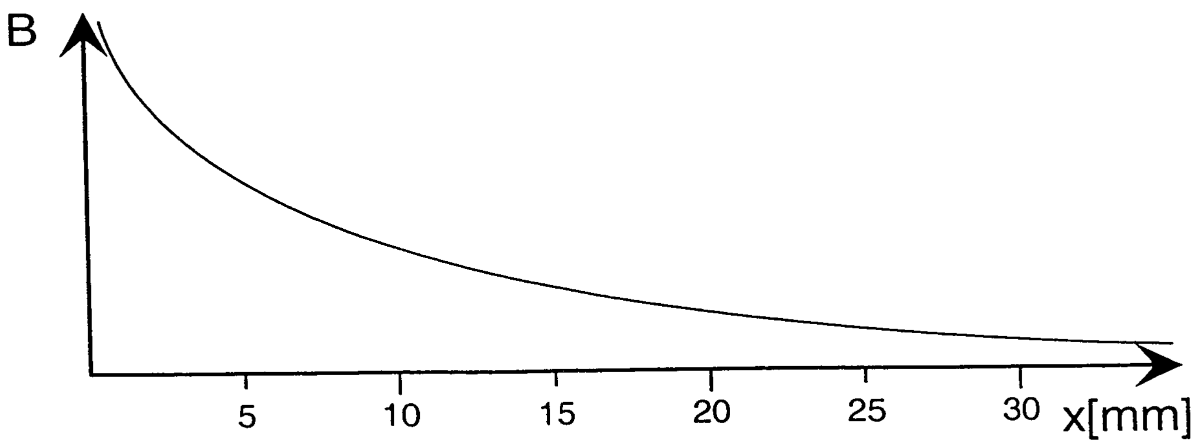

FIGURE 1C

PRIOR ART

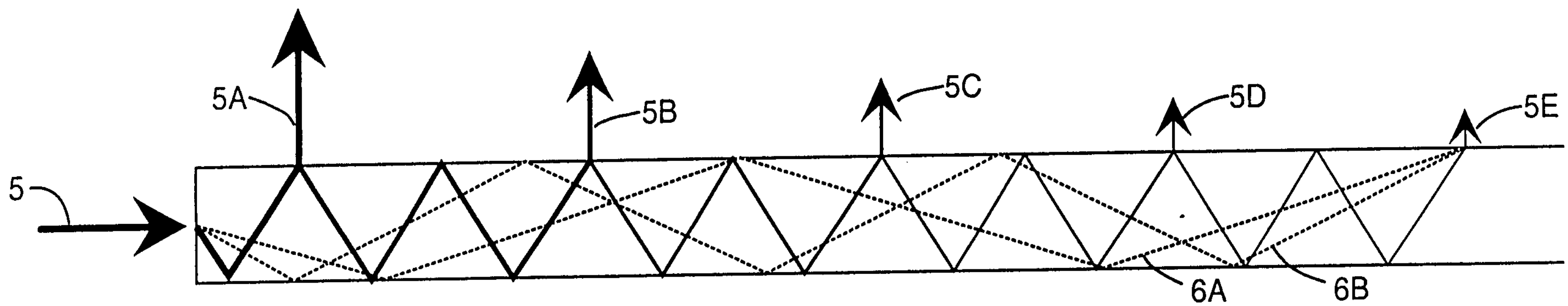

FIGURE 1D

PRIOR ART

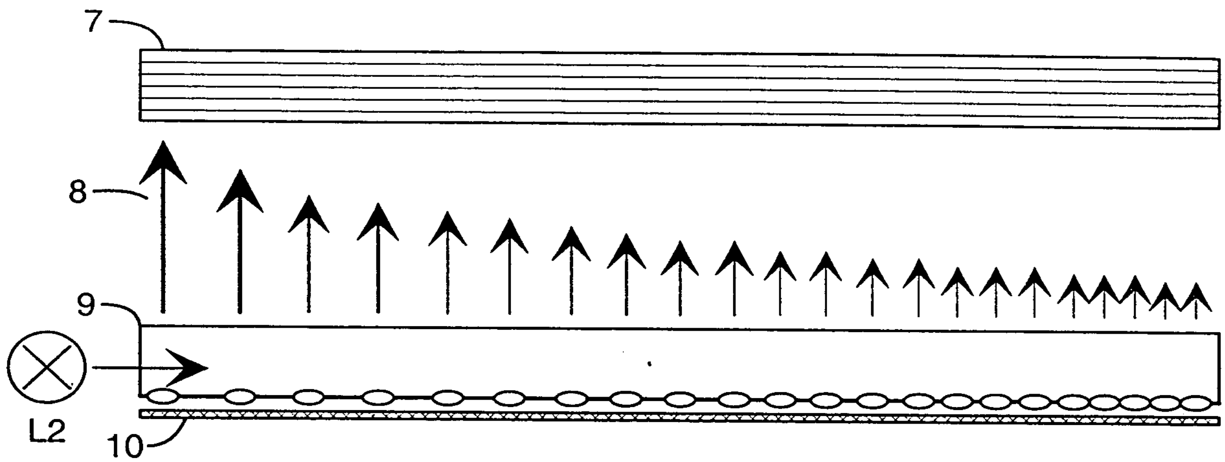

FIGURE 2

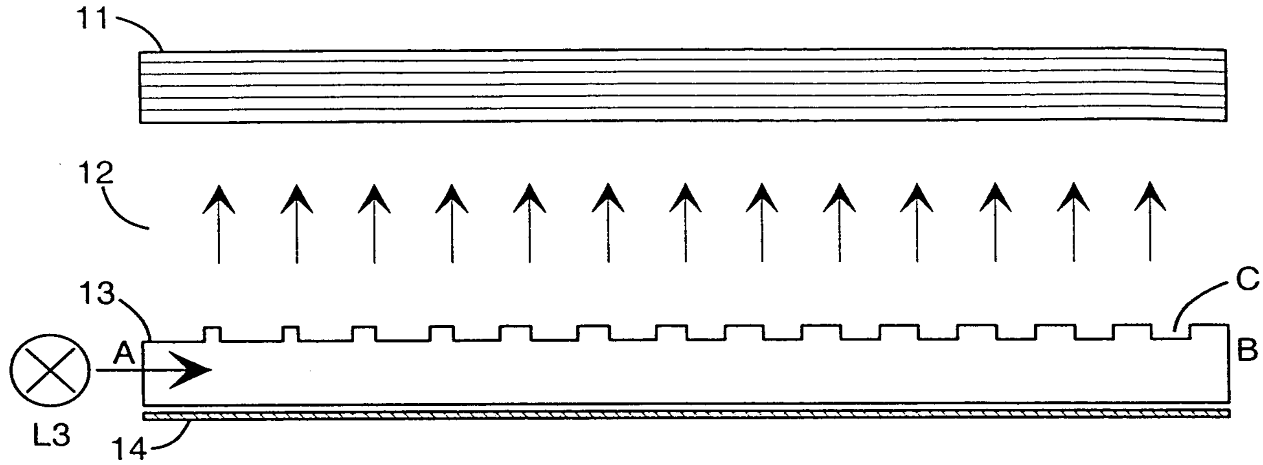

FIGURE 3A

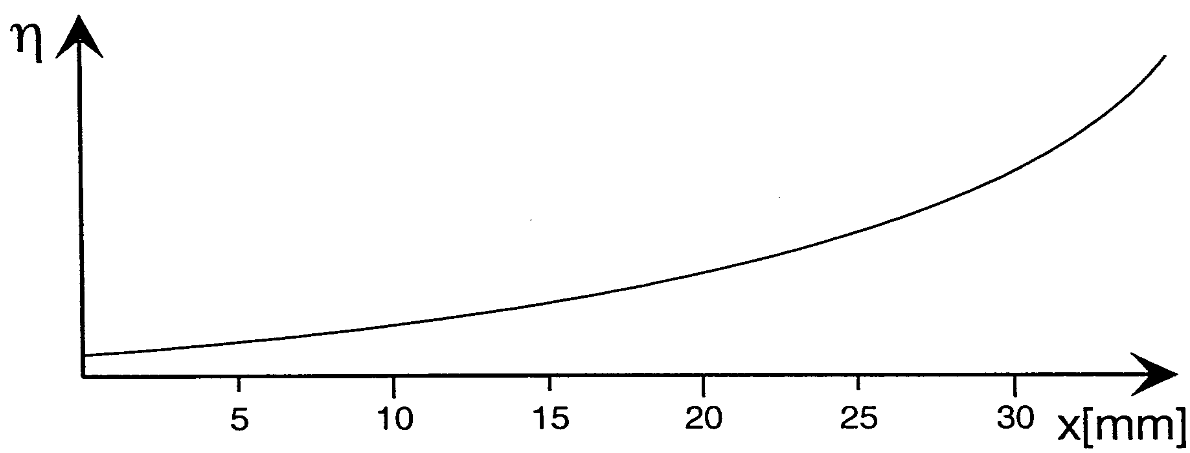

FIGURE 3B

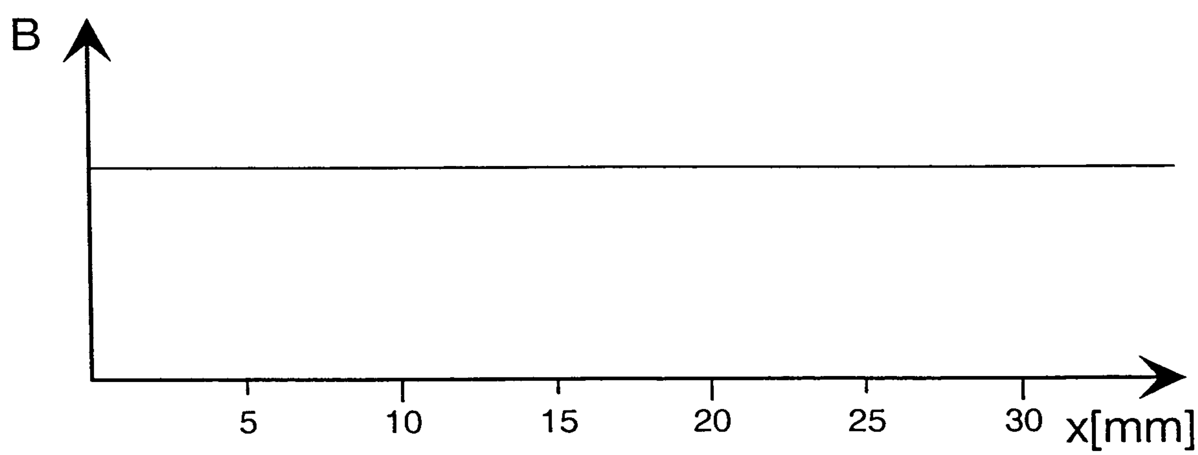

FIGURE 3C

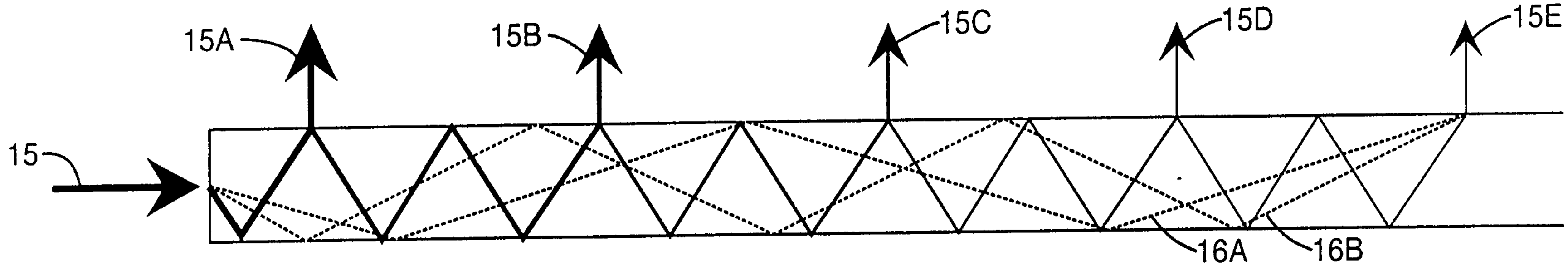

FIGURE 3D

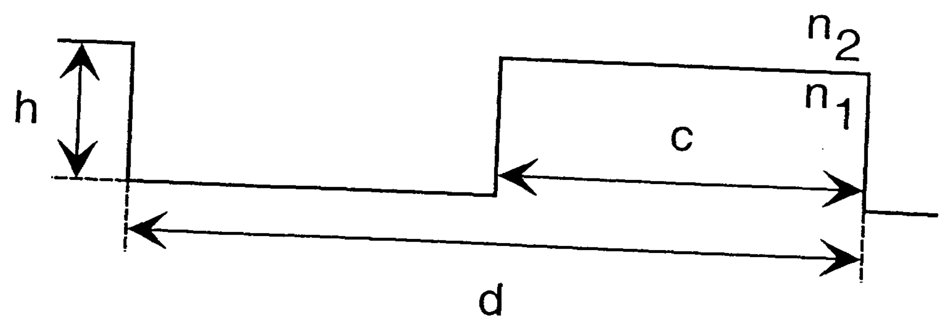

FIGURE 4

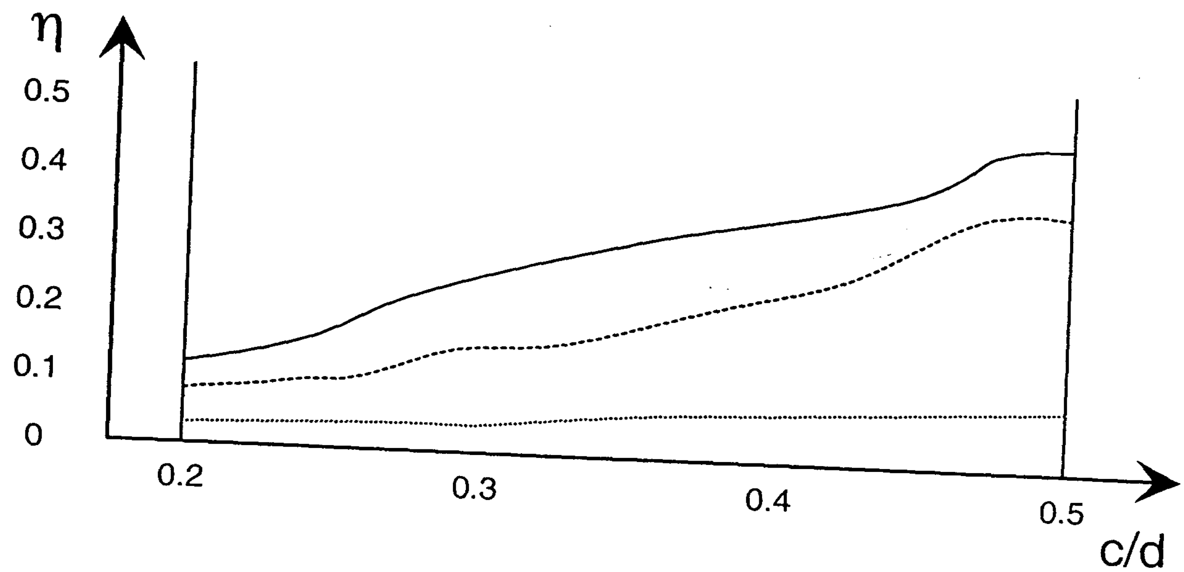

FIGURE 6

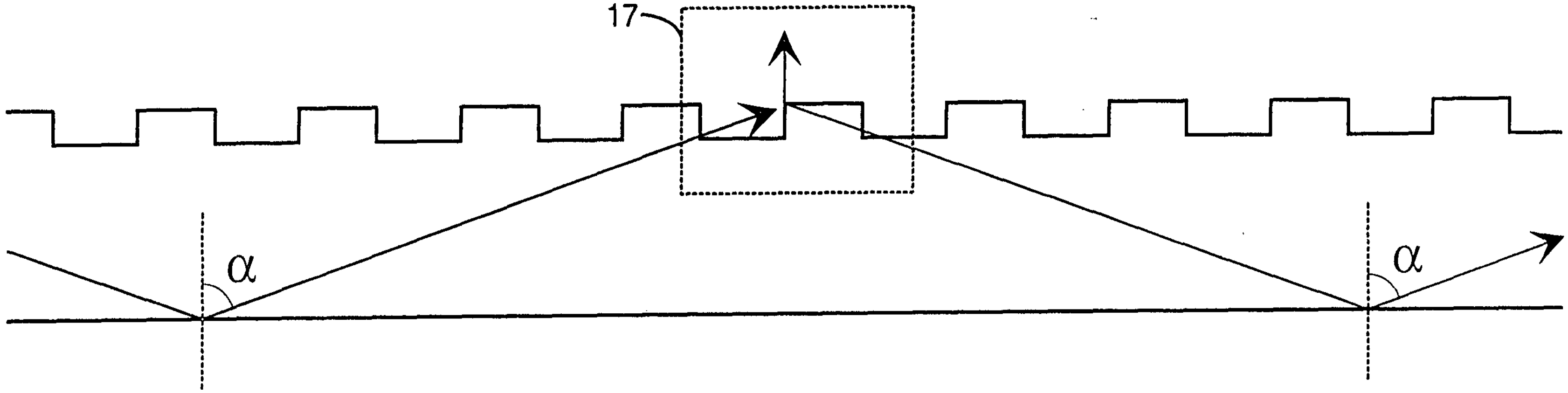

FIGURE 5A

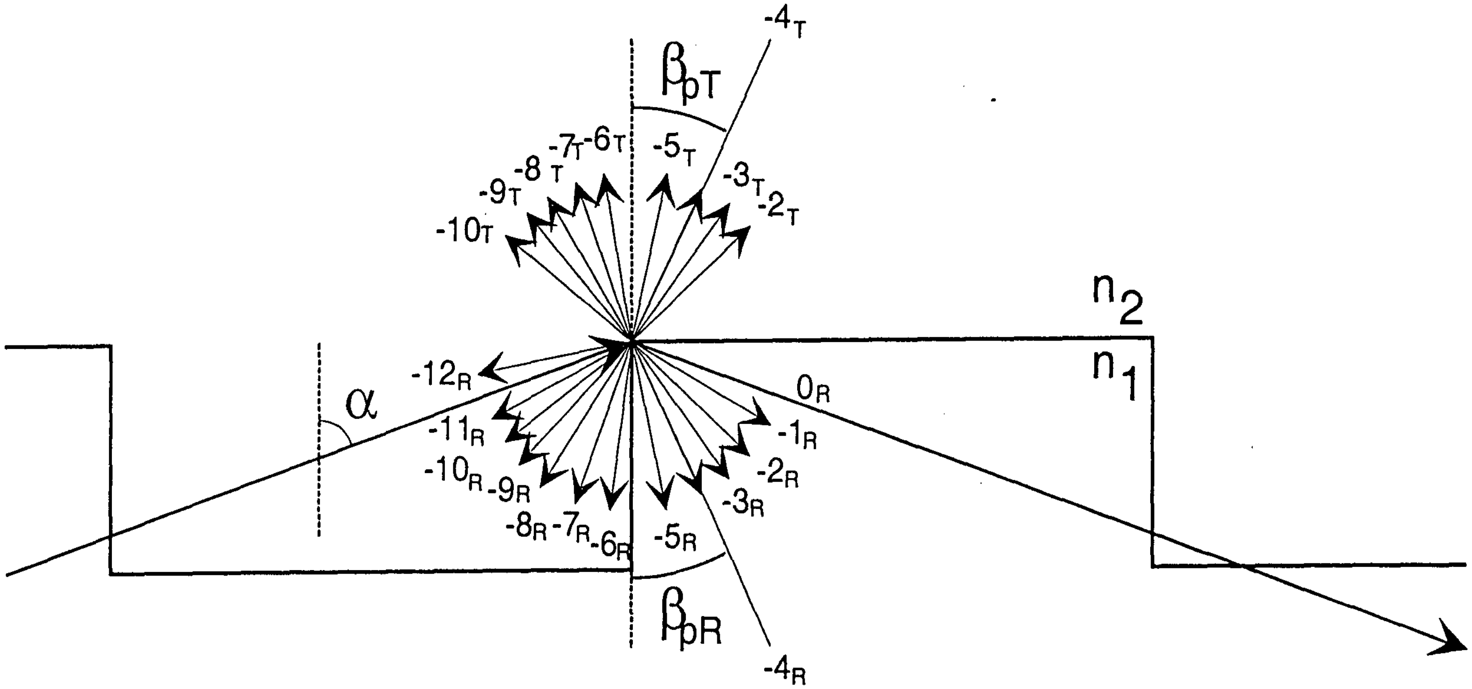

FIGURE 5B

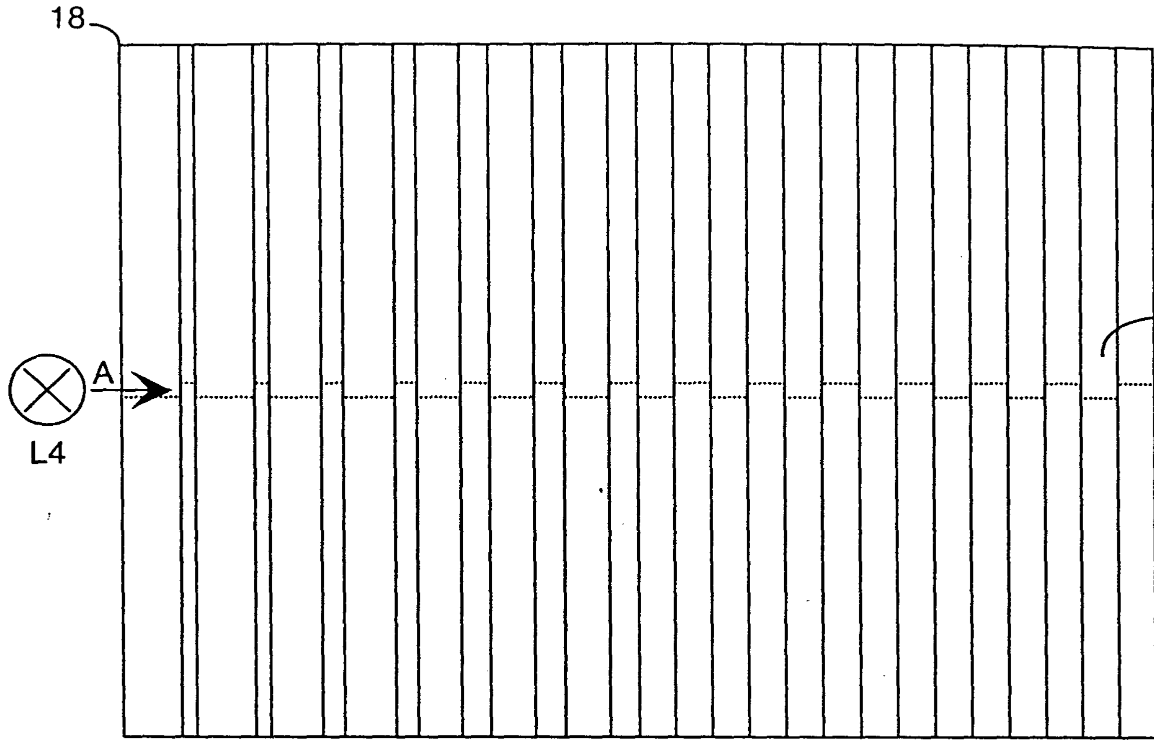

FIGURE 7A

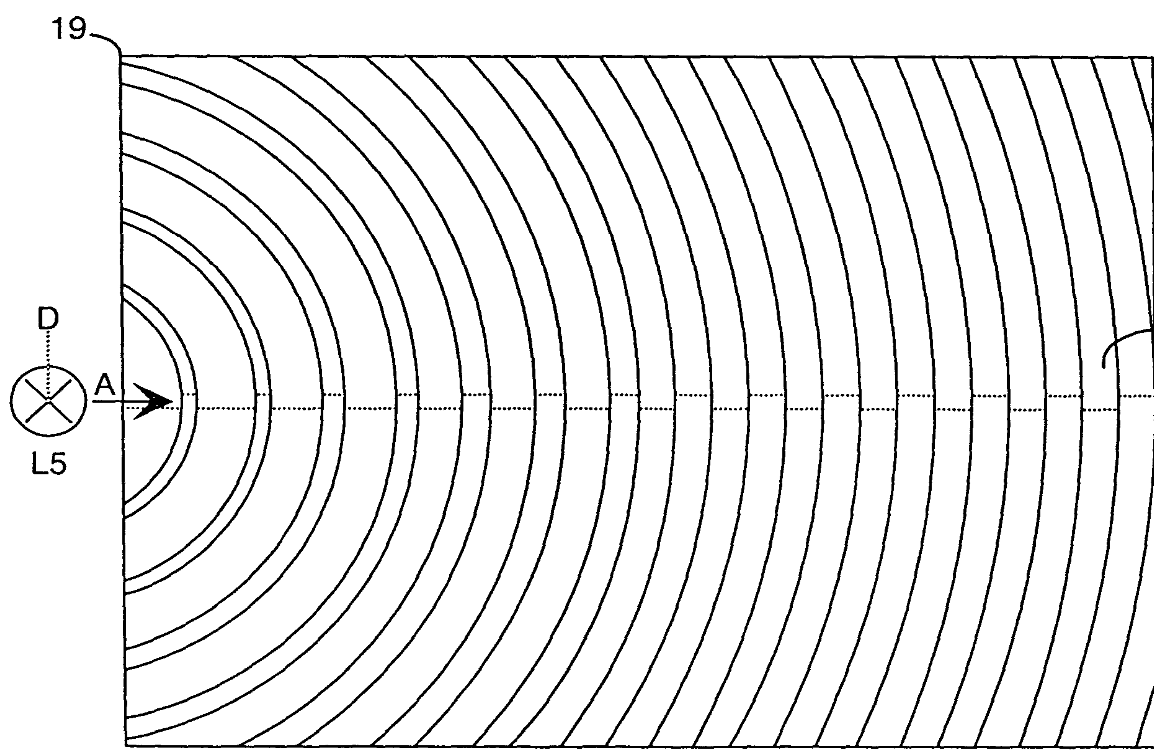

FIGURE 7B

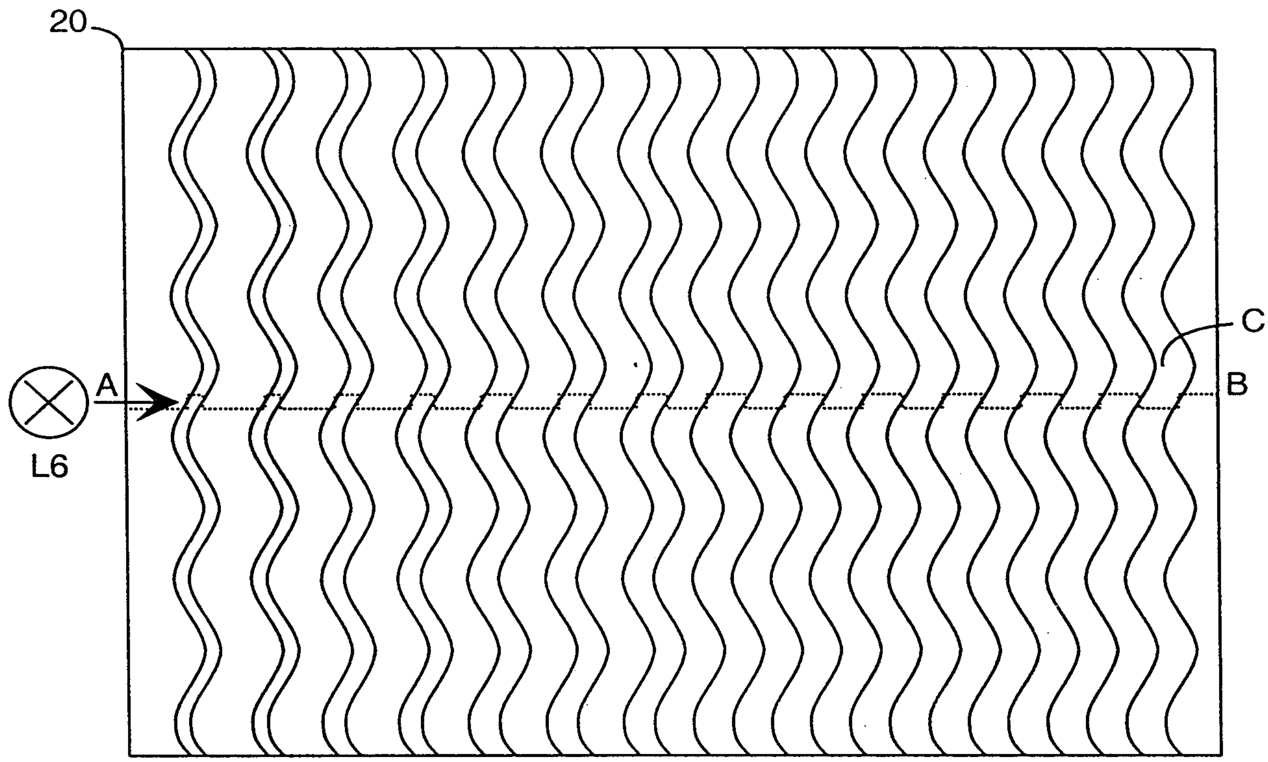

FIGURE 7C

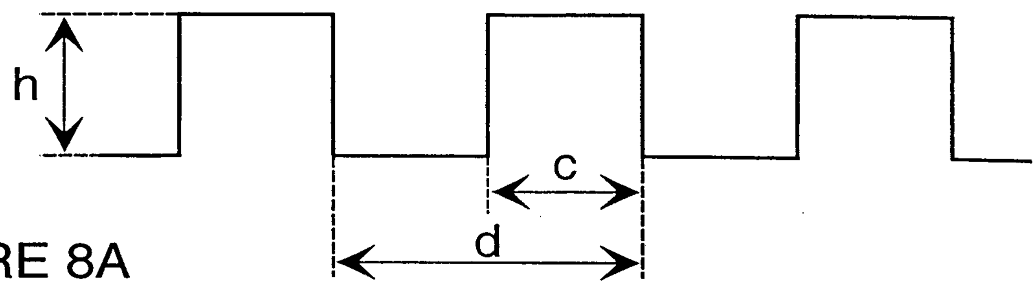

FIGURE 8A

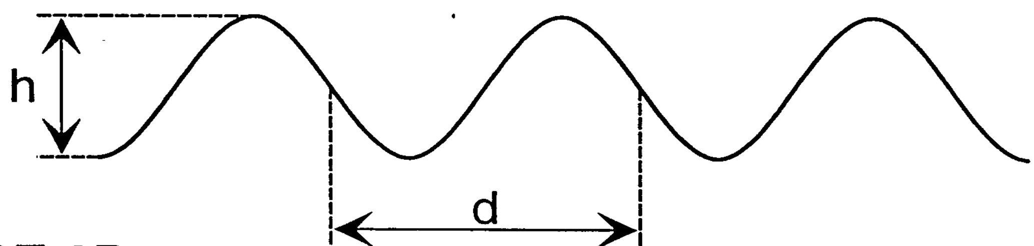

FIGURE 8B

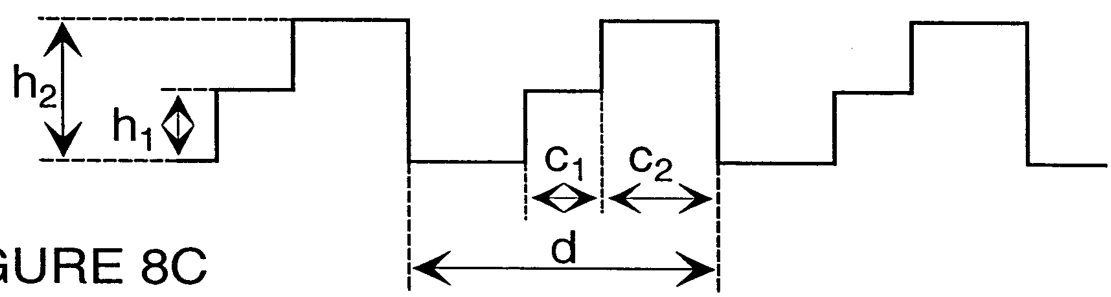

FIGURE 8C

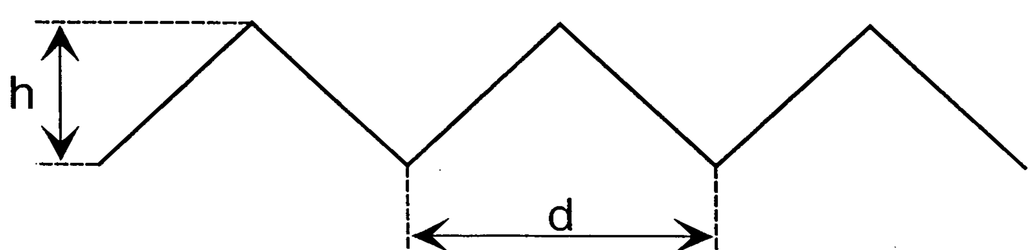

FIGURE 8D